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Access to Space: The Space Shuttle's Evolving Role

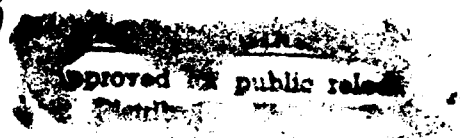
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Abstract

Access to space is of extreme importance to our nation and the world. Military, civil, and commercial space activities all depend on reliable space transportation systems for access to space at a reasonable cost. The Space Transportation System or "Space Shuttle" was originally planned to provide transportation to and from a manned Earth-orbiting space station. To justify the development and operations costs, the Space Shuttle took on other space transportation requirements to include DoD, civil, and a growing commercial launch market.

This research paper or case study examines the evolving role of the Space Shuttle as our nation's means of accessing space. The case study includes a review of the events leading to the development of the Space Shuttle, identifies some of the key players in the decision-making process, examines alternatives developed to mitigate the risks associated with sole reliance on the Space Shuttle, and highlights the impacts of this national space policy following the *Challenger* accident.

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Access to Space: The Space Shuttle's Evolving Role

I agree that there needs to be some kind of a capability in the event we do have some downtime in the shuttle program with one of the Orbiters and we're left with a fleet of three Orbiters. I think that's something that we need to think seriously about, and this country ought to make a decision on that particular point. I hope that situation never occurs, but you can't say that the probability is zero...

Jesse W. Moore
Associate Administrator
Office of Space Flight, NASA
Congressional Testimony, July 1985

INTRODUCTION

On January 28, 1986 the Space Shuttle *Challenger* exploded seventy-three seconds after liftoff from Launch Complex 39B at the Kennedy Space Center in Florida--approximately six months after Jesse Moore's testimony before the House Subcommittee on Space Science and Applications on "Assured Access to Space During the 1990's." The seven member *Challenger* crew perished in the explosion and with them the near-term quest for routine access to space. Following the accident, our nation's primary launch vehicle--the Space Transportation System (STS) or Space Shuttle--remained grounded for over 2½ years. As a result, national security, high value NASA scientific, and commercial payloads remained stranded on earth with no ride into space. After the *Challenger* accident it became very clear that the U.S. Space Policy developed in the 1970's and early 1980's was "flawed"--we had essentially put "all of our eggs in one basket." The

Complementary Expendable Launch Vehicle (CELV) initiative--which later became the Titan IV program--provided a much needed head start for the space launch recovery program initiated after the *Challenger* accident.

In light of the *Challenger* disaster and subsequent extended stand-down of the remaining Shuttle fleet, it is appropriate to review some of the events leading to the decision to rely solely on the Space Shuttle. We should also assess the consequences and impacts of formulating a space policy which relied almost entirely on the Space Shuttle for our nation's access to space. There is no doubt that the Space Shuttle program has enhanced U.S. world leadership in space exploration, and in addition has had a positive impact on our prestige among nations. However, a national policy that placed essentially sole reliance on one system for access to space, also placed extreme risks to national security, scientific exploration, commercial space programs, and the general health of U.S. space infrastructure and the associated industrial base.

WHY THE SPACE SHUTTLE?

Life After Apollo for NASA

In the late 1960's, when the U.S. was pursuing the goal of landing a man on the moon and returning him safely to earth (Apollo program), future space planners began to look at

alternative means of access to space. In February 1967, the President's Science Advisory Committee recommended that studies be made *"of more economical ferrying systems, presumably involving partial or total recovery and use."*¹ In September 1969, two months after Neil Armstrong set foot on the moon, NASA submitted a report to a "Space Task Group," set up by President Nixon, providing recommendations for the future goals of the U.S. space program. The recommendations included the development of a reusable space transportation system that could shuttle back and forth between Earth and space.²

NASA's Centerpiece. The proposed "Space Shuttle" would provide the transportation support for NASA's larger goal of an Earth-orbiting space station. However, it was clear at the time that funding on the order of the Apollo program was not going to continue. In March 1970, President Nixon endorsed NASA's long-range goal for a space station but deferred its approval pending development of the Space Shuttle.³ Responding to the issue of fiscal constraints, Dale D. Myers, the NASA Associate Administrator in 1971 stated:

*It took us some time to face up to the fact that wide open manned exploration of the planets and outer space was just not in the cards after the conclusion of Apollo--and that the country was not ready to support Apollo-sized space budgets [\$21.3 billion].*⁴

Carl H. Dry, Executive Assistant in NASA's Space Shuttle office at the time, stated:

Initially, we thought of the shuttle only in terms of the [space] station; now the shuttle is to the fore alone.⁵

So, instead of being the transportation element of NASA's planned space station, the Space Shuttle became the centerpiece of NASA's future programs. President Nixon's initial endorsement in 1970 started two years of effort to study various Shuttle configurations and initiated a national debate on the need for such a vehicle.

Shuttle Advantages. In February 1971, Leroy E. Day, Deputy Director of NASA's Space Shuttle Office, listed several advantages of the proposed new space transportation system:

- *A significant reduction--by a factor of ten--in the cost [\$1,000 down to \$100 a pound]⁶ of delivering men and payloads to near-earth orbit*
- *An easier launch and reentry environment, further reducing the cost of payloads and allowing transport of men and women who have not undergone the rigorous training now required of astronauts*
- *A more flexible capability to orbit a broad spectrum of manned and unmanned payloads and also to support high-earth orbit and planetary missions*
- *International participation in the project, including underwriting by other nations of part of the development costs.⁷*

NASA later broadened the utility of the Space Shuttle by emphasizing other mission areas to include: on-orbit servicing of spacecraft; retrieval and return of spacecraft for refurbishment and reuse; and the capability to meet future DoD requirements.

Early Debate

Intense national debate preceded Presidential and Congressional approval for Space Shuttle development. A great deal of this debate took place in Congress before Senate and House Committees responsible for NASA's budget. Senator Walter F. Mondale (D Minn) was the chief critic of the Space Shuttle in the early 1970's. To support his arguments against the Shuttle program, Senator Mondale submitted a previous statement by Dr. Robert Seamans, Jr., then Secretary of the Air Force, during Senate Hearings on June 29, 1971:

I cannot sit here this afternoon and say that the space transportation system is an essential military requirement. I think--I believe that it is important to national security. I hope it goes ahead. But it is not in the same category with systems like the B-1 and the F-15 and the Minuteman programs that we have a hard time funding as it is. So I saw little opportunity to also have a major space vehicle development system as part of the Air Force budget.⁸

However, Dr. Seaman's supported NASA's efforts to develop the Space Shuttle if the desired performance and cost benefits could be achieved. In earlier Senate hearings held on March 30, 1971, Dr. Seamans stated:

.... When the operational system [Space Shuttle] is achieved, we would expect to use it to orbit essentially all DoD payloads, "phasing out" our expendable booster inventory with the possible exception of very small boosters such as the Scout.... However, changeover must be accomplished without disturbing military mission capability and at minimum costs.⁹

Senator Mondale had strong misgivings about the cost of the Shuttle program in relation to other national priorities. Included in his June 1971 Senate testimony were the following remarks:

... I think the American public is becoming greatly concerned about the growing national budget and particularly concerned about the space budget.... The shuttle is nothing more than a transportation system. If you take NASA's advice and fund this project, we will be spending far more on a transportation system to serve near-earth orbit than we will be spending for the mass transit needs of the American population. If we spend what NASA is seeking on this space shuttle alone, we will be spending four times more than the combined annual expenditure to fight crime, pollution, and cancer.¹⁰

Besides the economic aspects of the proposed Shuttle program, there were significant concerns by some about the vulnerability of the Shuttle and risks that would be incurred should the system be developed and utilized as envisioned. These concerns were expressed in the same June 1971 Senate Hearings by Dr. Thomas Gold; Director, Cornell University's Center for Radiophysics and Space Research, consultant to NASA and member of NASA's Lunar and Planetary Missions Board, and member of the Space Sciences Panel of the President's Science Advisory Committee:

... It is very much a policy of putting all one's eggs in one basket, and a very insecure basket at that. It seems to me quite certain that there is a major omission in the economic surveys; namely, that there will continue to be a need to launch into earth orbit by means of expendable boosters, and that, therefore a parallel program will be kept going.... Even without considering warfare or sabotage, one would have to be concerned that technical faults or accidents could completely interrupt the entire space program, military and civilian, for long periods of time. A disaster like the Apollo fire, or a fault as on the Apollo 13 flight, would cause the shuttle system to be grounded until the causes are analyzed and cured, and the

country could not accept such interruptions in its space program.... So it seems to me absolutely clear the military must insist, in the national interest, to keep going on an entirely parallel system of launch capability...

NASA, in a written response to Dr. Gold's testimony, said that his statement addressed "matters largely outside his experience and competence as a space scientist."¹¹

Senator Mondale continued to apply pressure on the program by arguing that NASA's rationale for the Shuttle was misguided and the product of two factors:

- *The desire of a large, overgrown NASA bureaucracy to perpetuate itself*
- *NASA's desire to continue an active manned space flight program which has been cleverly disguised--out of political necessity--with arguments that the shuttle is utilitarian for unmanned missions.*¹²

In support of the Shuttle program, Senator Frank E. Moss (D Utah), made the following statement on the Senate floor in June 1971:

The Space Shuttle will bring new capability to military and civilian space programs by replacing all present expendable launch vehicles and carrying spacecraft into orbit for the U.S. Weather Bureau, the communications industry, the NASA space program and the Department of Defense.

Along with the continued national debate on the merits of the program, engineering and configuration trade studies moved ahead. The DoD began to play a larger role by influencing the early design and levying specific performance requirements on the Space Shuttle.

Space Shuttle Design. The initial conceptual design was a two-stage "fully reusable" system. However, high development costs (estimated at \$10-\$13 billion) drove designers to seek less expensive options. By the end of 1971 NASA was recommending a fully reusable manned orbiter powered by liquid propellant rocket engines fed by an expendable external tank and boosted by strap-on, recoverable and reusable booster rockets utilizing either a solid or liquid propulsion system. In January 1972, President Nixon approved the development of the Space Shuttle, recommending that:

...the United States should proceed at once with the development of an entirely new type of space transportation system designed to help transform the space frontier of the 1970's into familiar territory.... It will revolutionize transportation into near space by routinizing it.... It will take the astronomical costs out of astronautics.¹³

Final Configuration. The final configuration--consisting of an orbiter, external tank, and solid rocket motors--was selected in March 1972. Although liquid rocket boosters offered potential savings in operating costs, solid rocket motors were selected primarily because of their lower development costs and reduced technical risks. NASA's cost estimate for this configuration was \$5.2 billion (1971 dollars)--about half the cost of the original fully reusable design. This shuttle configuration offered lower development costs while retaining acceptable levels of reusability at the expense of higher operating costs.

The Space Shuttle payload bay would be sixty feet long by fifteen feet wide and would be capable of lifting 65,000 pounds of cargo to low earth orbit on an easterly launch azimuth (lift capability up to 40,000 pounds to polar orbit inclinations). On its return to earth from orbit, the Shuttle Orbiter would have a cross-range maneuvering capability of eleven hundred nautical miles. The launch rate for a four orbiter fleet would be as high as sixty flights per year with a recurring cost per flight of approximately \$10.5 million (1971 dollars). The planned first flight of the Space Shuttle was projected for 1978.

Other Alternatives

During the early 1970's (1970-1973) other launch alternatives were assessed by NASA and industry. NASA's own in-house study, which compared the costs and benefits of the Shuttle with those of existing and possible future expendable launch vehicles (ELV's) showed some distinct economic advantages for the Shuttle.¹⁴ Other economic assessments performed by NASA contractors also showed favorable economic benefits for the Space Shuttle. These favorable economic assessments assumed that the cost savings due to reusability (both the transportation system and payloads) would outweigh the costs associated with operating a manned system.

Mathematica Report. In March of 1970, NASA contracted a consulting firm, Mathematica Inc., to perform a cost comparison

of the Shuttle program against both current and new expendable launch vehicles. Mathematica Inc. presented its results to NASA in May 1971. The analysis indicated that the proposed Shuttle system would be more economical than either current or improved expendable boosters, primarily because of savings in payload construction (i.e., fewer payloads constructed, since those placed in orbit could be serviced or brought back to Earth for refurbishment) and transportation system operating costs (Figure 1). The \$4 billion estimated savings from 1972 to 1990 was based on the assumption that 514 missions would be launched between 1979 and 1990.¹⁵ The counter argument was how realistic were these flight requirements, given the previous statements about spacecraft reusability.

NASA Revises Mission Model. After the Mathematica Report was released, NASA revised the Shuttle Mission Model (flight forecast) upward to 581 flights. The next revision to the mission model, which was released in April 1973, forecasted 779 flights for the Shuttle from 1979 to 1991 (approximately sixty flights per year over the period). To put this flight rate in perspective, it is interesting to note that in 1972--the year before these hearings were held--the U.S. launched thirty-three expendable boosters.¹⁶ NASA's own assessment of this model indicated a savings of \$16 billion when compared to using current ELV's. Included in the Shuttle estimate was the cost of five Shuttle Orbiter vehicles at a cost of \$250 million each.¹⁷ A large portion of the cost savings was attributed to reduced

payload costs for those on the Shuttle. NASA also believed that many payloads would be recovered, refurbished, and reused or serviced on-orbit thus decreasing recurring spacecraft expenditures.

GAO Assessment. In 1972 and 1973, at the request of Senator Mondale, the General Accounting Office (GAO) prepared an "Analysis of Cost Estimates for the Space Shuttle and Two Alternate Programs." The GAO findings were presented during Senate Hearings of the Subcommittee of the Committee on Appropriations on June 12, 1973. This was the first time that a major review and cost estimate analysis had been conducted by the GAO at such an early stage in a major technological program.¹⁸ The GAO report focused primarily on cost considerations, however, the report also pointed out several valid non-cost issues which they felt should receive consideration as well:

- *Whether the space programs rank sufficiently high among national interests to justify the commitment to develop and procure the Space Shuttle. This depends on whether the U.S. will need and want to make substantial use of space in the years to come--not just to 1990 or 1991 but for the indefinite future.*
- *Whether the values of the new technology that might result from the Space Shuttle Program would justify its selection.*
- *Whether the Space Shuttle offers unique capabilities and the kind of flexibility which the U.S. should have.*
- *Whether the prestige the U.S. might get from development and use of the Shuttle would justify its selection.*
- *Whether it is in the national interest to commit the Nation to extensive manned space flight when some think that manned flight is not necessary to achieve scientific objectives and when the space program could be adversely affected by public reaction if lives were lost.*

In the economic area, the GAO pointed out that the fundamental difference between the Shuttle and ELV's is that the Shuttle is reusable. Therefore, the Shuttle can be shown to be more cost effective as the flight rate increases. The fewer the flights, the smaller the advantage of a reusable system and the more attractive expendable systems become from a cost standpoint.¹⁹ A key point made by the GAO in their report was the associated issue of funding for the 779 missions included in NASA's latest mission model, i.e. who is going to supply (fund and build) the payloads and spacecraft to support a flight schedule of one launch a week continuously for at least a thirteen year period? If a significant number of the missions are not funded then the ELV option could prove to be the better approach--economically. The GAO's bottom line was summed up in the following statement:

*We are not sure that the Space Shuttle is economically justified. We do not consider it prudent to place too much confidence in the projected cost savings. Our review suggests that a congressional decision to continue the Space Shuttle program should be made on other than economic grounds.*²⁰

Senator Frank Moss, agreed with the GAO report with respect to not approving the program on its cost saving potential alone, arguing that the Shuttle's fundamental advantage and use would be "to provide routine access to space."²¹ Senator Barry Goldwater (R Ariz), labeled the GAO report as "a hodgepodge of indecision, innuendo and irrelevancy."²²

The fiscal 1974 NASA budget authorization was crucial for the continuation of the Space Shuttle program. On July 11, 1973, Congress approved NASA's budget request of \$475 million for continued Space Shuttle research and development.

West Coast Launch Site

In April 1974, NASA and the DoD selected Vandenberg Air Force Base to support the demand for DoD and NASA polar launch requirements. In 1974, the Air Force determined that conversion of existing, partially completed Titan III facilities, left over from the cancelled Manned Orbiting Laboratory program, could save \$100 to \$300 million dollars over the construction of new Shuttle facilities.²³ In the sixty flight per year mission model, 20 flights were planned from the West Coast facility. The planned West Coast capability was later reduced to no more than ten flights per year and by 1984 the estimate was down to four flights per year.

Major DoD Investment. The construction and operation of the Vandenberg Shuttle facilities was one of the major DoD contributions to the program and in the end represented a significant investment. Cost estimates for the Vandenberg Shuttle launch facility were originally set at \$251 million. This rose to \$435 million in 1982 and by 1987 total DoD expenditures for the Shuttle facilities at Vandenberg had risen to \$3.1 billion. Vandenberg Shuttle facilities included:

upgrades to the existing airfield; orbiter maintenance and checkout facility; hypergolic maintenance facility; mate/demate facility; integrated operations support complex; flight crew accommodations facility; launch facilities at Space Launch Complex 6 (SLC-6) with its mobile service tower and Shuttle Assembly Building; external tank receiving and processing facilities; and a solid rocket booster processing facility. In addition, solid rocket booster recovery facilities were constructed at Port Hueneme, 85 miles south, near Oxnard, California. The initial operating capability (IOC) was set for December 1982 but was delayed several times before IOC was finally declared in late 1985.

In With the New, Out With the Old

Space Shuttle Highs and Lows. In the 1970's Space Shuttle development continued, although delays were incurred due to funding shortfalls and technical challenges--primarily with the thermal protection system (30,000 tiles) and the Shuttle main engines. In 1977, the Orbiter *Enterprise* was used to conduct captive (mounted piggyback atop a modified Boeing 747) and free-flight tests at Edwards AFB to evaluate flying qualities and guidance and control systems. Integrated Shuttle systems tests, including vibration testing of the complete assembly--orbiter, external tank and solid rocket boosters--were conducted in 1977-1980 at Marshall Space Flight Center in Alabama.

In 1981, the Space Shuttle *Columbia* was ready for the first launch and to begin the orbital test flight program. This program was originally planned for six missions but was later reduced to four. On April 12, 1981 (three years later than originally planned) *Columbia* was launched from Kennedy Space Center and landed two days later at Edwards AFB in California. After three more successful orbital test flights in 1981 and 1982, the Space Shuttle was declared "operational."

The Space Shuttle fleet expanded to four operational orbiters--*Columbia*, *Challenger*, *Discovery*, and *Atlantis*--that flew twenty-four successful missions between April 1981 and January 1986. *Challenger* had flown nine times prior to its tragic last flight on January 28, 1986. In the twenty-four flights prior to the *Challenger* accident, the Space Shuttle demonstrated its capability to perform a variety of missions to include deployment of payloads, retrieval and repair missions, and as a platform for the study of space science.

Space Policy Evolution. With President Nixon's 1972 approval of the Space Shuttle development, the long-range plan for meeting U.S. access to space requirements steadily moved towards a policy of sole reliance on the Shuttle. This meant phasing out ELV's which had been in use since the first U.S. satellite launch in 1958. In the late 1970's, with the Space Shuttle still under development, U.S. National Space Policy continued to focus on the Space Shuttle as the primary means of accessing space for Civil,

DoD, and even commercial satellite requirements. The ever increasing Shuttle program costs were making it more important than ever to increase the number of users and flights in order to further amortize the development costs--and to reduce the projected payback period. Payloads from all user communities (Civil, DoD, and commercial) were now being designed to fly almost exclusively on the Space Shuttle instead of ELV's.

NSC Policy Review Committee. In 1978, President Jimmy Carter directed the National Security Council Policy Review Committee to "*review existing policy and formulate overall principles which should guide our space activities.*" On June 20, 1978, President Jimmy Carter released the results of this review in the form of a Presidential Directive. This directive established national policies to guide the conduct of U.S. space activities and programs. Included in this Presidential Directive were guidelines for the utilization of the Space Shuttle:

The United States will develop, manage, and operate a fully operational Space Transportation System (STS) through NASA, in cooperation with the Department of Defense. The STS will service all authorized space users--domestic and foreign, commercial and governmental--and will provide launch priority and necessary security to national security missions while recognizing the essentially open character of the civil space program.²⁴

The National Security Council staff prepared many of the space policy directives during the Carter Administration. Frank Press, the President's Science Advisor, also played a key role in

defining responsibilities for various government agencies in space related activities.²⁵

Space Policy Shift. President Reagan's 1982 Space Policy, released on July 4, 1982--STS-4 landing day (last orbital test flight)--continued the strong commitment to the Space Shuttle:

- *The United States Space Transportation System (STS) is the primary space launch system for both national security and civil government missions....*
- *... The first priority of the STS program is to make the system fully operational and cost-effective in providing routine access to space.*
- *United States Government spacecraft should be designed to take advantage of the unique capabilities of the STS. The completion of transition to the shuttle should occur as expeditiously as practical.*²⁶

However, the 1982 policy also left the option open for continued use of ELV's:

- *Expendable launch vehicle operations shall be continued by the United States Government until the capabilities of the STS are sufficient to meet its needs and obligations. Unique national security considerations may dictate developing special-purpose launch capabilities.*²⁷

Hedging Our Bets. In the early 1980's the DoD, specifically the Air Force serving as the DoD's executive agent for space, began to express concerns about the risk to national security requirements through total dependence on the Space Shuttle. Edward C. Aldridge, Jr., then Under Secretary of the Air Force, began to articulate the need for a limited number of ELV's for use by the DoD. These space boosters became known as Complementary Expendable Launch Vehicles (CELVs) and would have a

performance capability equivalent to the Space Shuttle. The CELV's were planned for use during the transition and early operational period of the Space Shuttle. Mr. James M. Beggs (NASA Administrator in 1984) and some members of Congress expressed concern that the DoD use of ELV's could have a major impact on the Space Shuttle program. In Congressional Hearings, Mr. Beggs indicated that he could not *"gainsay the need of the DoD to have an assured launch capability."* However, in his opinion, a Shuttle-derived vehicle could best provide this backup capability.²⁸

Presidential Support. Debate within the Administration on the CELV issue continued even after President Reagan's February 1985 release of National Security Decision Directive (NSDD 164).²⁹ This directive clarified DoD's commitment to the Space Shuttle, i.e., the DoD would utilize at least one-third of the Shuttle's available flights over the next ten years. However, the directive also made provisions for Air Force acquisition of ten CELV's for use between 1988 and 1992. In hearings before the Senate Subcommittee on Science, Technology, and Space in April 1985, Under Secretary Aldridge provided additional rationale for the CELV's when questioned by Senator Gorton (R Wash) on the likelihood and under what circumstances more than ten CELV's might be required:

The only conditions I can think of where we would need more than ten [CELV's] are if we had a major failure in the Shuttle program, if one of them crashed or we had to ground the Shuttle fleet for a long period of time until we resolved a problem.

Mr. Aldridge's testimony turned out to be extremely prophetic ten months later when the *Challenger* accident brought many of our space policy shortcomings into sharp focus. At the time, however, in addition to ensuring our nation's future ability to access space by reducing reliance on a single transportation system (i.e., the Space Shuttle), the CELV initiative also served to maintain the U.S. industrial base by keeping launch vehicle production and assembly lines open. Costs remained an issue but national security concerns were strong enough to continue this initiative.

Conflicting Views. Mr. Aldridge's philosophy was in stark contrast to opinions expressed by Dr. Hans Mark--Chancellor of the University of Texas System and both a former Deputy Administrator of NASA and Under Secretary of the Air Force--during his July 1985 Congressional testimony in joint hearings on "Assured Access to Space during the 1990's":

It is my considered opinion that there is no technical reason why the entire U.S. space launch capability should not be vested in the Space Shuttle fleet.

He also indicated that in his view, arguments in favor of creating the CELV are "flawed" and further:

The real issue...is not reliability or vulnerability. ...[It] is operational control of the launch vehicles.... It is unacceptable that the people in charge of the most important space payloads we fly do not have operational control over their own space vehicles.³⁰

Dr. Mark also expressed that in his opinion, all Titan, Delta, and Atlas launch vehicles, as well as, the proposed CELV's, should be "*phased out by the 1990's.*"³¹

General Robert T. Herres, then Commander in Chief of the North American Aerospace Defense Command and Commander of the Air Force Space Command, testifying before the same joint hearings stated:

Expendable launch vehicles add dimensions to our inventory of boosters that would not be otherwise available if we depended solely on the Shuttle vehicle and the Shuttle series of vehicles alone. There is a risk reduction by depending on a separate kind of system that has different "long poles in its tent," so to speak, from those that exist with a single system.

This July 1985 testimony--over thirteen years after the decision to build the Space Shuttle and six months prior to the *Challenger* accident--indicated that a lot of concern existed in some circles of the government on just where earlier policy decisions had now led us.

IMPACTS and CONSEQUENCES

Flight Rate Declines. The impacts of relying solely on the Space Shuttle for U.S. access to space became evident even before the 1986 *Challenger* accident. The Shuttle's first flight occurred in April 1981, three years later than originally planned. As late as 1978, NASA was projecting flight rates up to fifty-eight flights per year (Figure 2) distributed between launches from the Kennedy Space Center (Eastern Launch Site) and Vandenberg AFB

(Western Launch Site). By 1985, these early flight rate goals were being scaled down to a total of about twenty-four flights per year for a four Orbiter fleet, with an ability to surge temporarily to a rate of twenty-eight flights per year.³²

Following the *Challenger* accident annual flight rates were set at no more than twelve flights per year. Eight Shuttle flights are currently planned for calendar year 1993.

Increases in Launch Costs. Space Shuttle launch costs have increased steadily since the program was initiated in the early 1970's. In 1971 costs per flight were estimated at \$10.5 million, in 1975 the rate was estimated at \$18 million, and in 1988--\$250 million³⁵ (all costs in then year dollars). The current 1993 cost per flight estimate is \$420 million (\$380 million for operations plus \$40 million for civil service personnel) for each of the eight planned flights.³⁴ NASA's overall investment in the Space Shuttle totaled \$30 billion by 1982.³⁵ Expenditures to date are estimated at nearly \$80 billion.³⁶

Lost Investment. Another significant impact was the lost Shuttle launch capability from the West Coast--SLC-6 at Vandenberg AFB. With a reduced orbiter fleet it became apparent to NASA and the DoD that it would not be reasonable to support Shuttle flights from two launch sites. Therefore, the decision was made to discontinue the seven year West Coast launch site development effort--losing a DoD sunk cost of \$3.1 billion.

Launch Delays Cost Big Dollars. In the wake of the *Challenger* accident and the resulting launch delays, it was estimated that by 1990 there would be a backlog of twenty-four equivalent Shuttle flights. NASA, DoD, and commercial payloads would all feel the impacts to on-orbit capabilities and program costs due to extended ground storage costs. Many of the payloads were within months of launch at the time of the accident. NASA payloads waiting for launch included high priority planetary missions (*Galileo* mission to Jupiter, *Magellan* mission to Venus, and the *Ulysses* mission to the Sun) and the Hubble Space Telescope. Among the most expensive spacecraft to maintain in storage was the Hubble Space Telescope. This spacecraft represented a \$1 billion investment and cost \$7 million a month to store, test, and maintain--the launch was ultimately delayed for approximately 2½ years.³⁷

Commercial Customers Turned Away. Up through the time of the *Challenger* accident and for a short period thereafter, NASA had signed contracts with numerous commercial customers for launch services aboard the Shuttle. Afterwards it became apparent that NASA could not support the needs of the commercial community along with high priority DoD and NASA scientific missions. President Reagan announced a fundamental change in U.S. space policy on August 15, 1986 when he declared that "*NASA will no longer be in the business of launching private satellites.*"³⁸ So, after some early success in the commercial launch market with the Shuttle, the nation lost its share of this business (no other

U.S. ELV's available to fill the gap) to other launch service providers--primarily the European Space Agency's Ariane booster.

Arianespace's early 1980's marketing strategy in the commercial launch market pointed out to prospective customers several deficiencies of the Space Shuttle to include:

- *The DoD enjoys absolute priority and at any moment can override any other satellite*
- *An "incident" on the Shuttle could immobilize the entire fleet and delay a launch for months*
- *The NASA estimates for turn-around time have always been optimistic and delays are likely*
- *Price increase is certain to occur--maybe as much as 50%.³⁹*

Following the *Challenger* accident, Arianespace was "in the right place at the right time" to attract many more commercial customers--the U.S. ELV industry would be a long time getting any of them back.

Flight Safety Concerns. A major impact to U.S. launch plans and capability involved the flight worthiness of the *Centaur* upper stage aboard the Space Shuttle. The *Centaur* was to provide boost capability from low earth orbit up to geosynchronous orbit for communications spacecraft or into interplanetary trajectories for scientific missions. *Centaur* would have been the first liquid oxygen/hydrogen powered upper stage to fly on the Shuttle. However, following the *Challenger* accident, the \$1 billion Shuttle *Centaur* effort was cancelled due to safety concerns.

This decision directly impacted all spacecraft programs that had plans to use the Shuttle/*Centaur* combination. *Galileo*, *Magellan*, and *Ulysses* required redesign to utilize alternate upper stages. Planetary missions were also affected due to increased trip times (caused by non-optimum trajectories and decreased upper stage performance) resulting in increased tracking time and costs. A two year trip time extension for the *Galileo* probe to Jupiter was estimated to cost \$100 million.⁴⁰

ROAD TO RECOVERY

A New Shuttle Orbiter for NASA. President Reagan announced on August 15, 1986 that the U.S. would start building an additional Orbiter to replace *Challenger*.⁴¹ Congress allocated \$2.1 billion for a new Orbiter, \$36 million for replacement of inertial upper stage and cradle equipment, and \$33 million for a replacement Tracking and Data Relay Satellite--lost with *Challenger*.⁴² NASA received \$2.4 billion from DoD funds in a Congressional transfer of budget authority .⁴³

More ELV's for the DoD. After the *Challenger* accident, the DoD moved swiftly to initiate efforts which would restore the U.S. space-lift capability for national security missions. The original buy of ten CELV's (Titan IV's) was increased to twenty-three, and later to forty-one vehicles with options for more through the late 1990's. The Air Force awarded a Medium

Launch Vehicle (MLV) contract to McDonnell Douglas for twenty Delta II's for the NAVSTAR Global Positioning System (GPS) satellites. Later, a MLV II contract was awarded to General Dynamics to develop the Atlas II ELV to launch ten Defense Satellite Communications System (DSCS) satellites. The previous effort to convert existing Titan II ballistic missiles for space launch use also continued.

These DoD ELV initiatives effectively removed all DoD payloads from the Space Shuttle--however, some remained in the near-term since it was not cost effective to redesign those spacecraft for ELV use. The total cost for the DoD Space Launch Recovery program was \$11.7 billion over the period from FY 1986 to 1994.⁴⁴

OBSERVATIONS

Space Policy Shortcomings. The major space policy decision in the 1970's was to move from reliance on ELV's to almost sole dependence on the Space Shuttle. There was little consideration given to an alternative means of access to space or the consequences that might be incurred in the event of an extended downtime for the Space Shuttle fleet. The space policy began to evolve--although not without some resistance--in the early 1980's, to include an access to space "insurance policy" in the form of complementary expendable launch vehicles. It became evident after the *Challenger* accident that U.S. Space Policy had not fully accounted for potential catastrophes that could ground

the only means of access to space for extended periods of time. The Space Shuttle became recognized as a significant national investment and should be utilized as a "national resource."

The next major change in policy did not come until President Bush released an update to the U.S. National Space Policy in November 1989. Space transportation was addressed in this policy, as well as other areas of U.S. space activity. The policy dictated that the Shuttle would be used for those missions which require either a manned presence or the other unique capabilities that it could provide. This policy also made the point that national security payloads would *"be distributed among launch systems and launch sites to minimize the impact of loss of any single system or launch site on mission performance."*⁴⁵

Lessons for the Future. After twenty-four successful flights, the Nation was lulled into a false sense of security by the seemingly routine nature of Space Shuttle operations. Our space policy assumed that catastrophic failures would not occur and therefore our space transportation strategy was not adaptable to unexpected events. As the nation now moves ahead in defining its long range goals and vision for future space exploration one area that will continue to receive emphasis is the method of accessing space. However, we should first define what it is that we want to do in space--and then build a transportation system that satisfies those needs. Risks should also be evaluated to ensure future access to space is not disrupted for extended periods.

Figure 1: Launch System Cost Comparison (\$B)
Mathematica Inc. Report -- May 1972

Cost Elements	Current ELVs	New ELVs	Shuttle
Launch Vehicle Costs			
Non-recurring (FY 1972-87)	\$1.62	\$2.00	\$7.60
Recurring (FY 1979-90)	\$10.60	\$8.76	\$5.40
Total Launch Costs	\$12.22	\$10.76	\$13.00
Payload Costs (Satellites)			
R&D (FY 1975-90)	\$11.00	\$10.60	\$9.88
Recurring (FY 1976-90)	\$18.80	\$18.40	\$12.70
Total Payload Costs	\$29.80	\$29.00	\$22.58
Total Program Costs	\$42.02	\$39.76	\$35.58

Source: Mathematica Report results presented in National Journal, August 19, 1972: p. 1328

Figure 2: SPACE SHUTTLE TRAFFIC MODEL
NASA - 1978

	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	TOTAL
ELS*														
NASA	1	6	10	10	18	17	19	18	15	17	17	16	3	167
U.S. GOVT	1	1			1				1		1	1		6
U.S. COM'L	1	3	1	2	3	4	5	4	9	8	8	4	2	54
FOREIGN		1	3	3	3	3	3	5	5	5	6	6	1	44
DOD			2	6	7	8	7	5	8	6	7	9	2	67
SUBTOTAL	3	11	16	21	32	32	34	32	38	38	39	36	8	338
REFLIGHTS			2	1	2	2	2	2	2	2	2	2	1	20
TOTAL ELS	3	11	18	22	34	34	36	34	40	38	41	38	9	358
WLS*														
NASA				1	4	6	5	5	6	4	6	6	1	44
U.S. GOVT				1	1	1	2	2	4	2	4	2	1	20
U.S. COM'L							1	1				1		3
FOREIGN							2	3	1	2	1	1	1	11
DOD				2	4	5	4	6	6	6	4	6	1	44
SUBTOTAL				4	9	12	14	17	17	14	15	16	4	122
REFLIGHTS						1	1	1	1	1	1	1		7
TOTAL WLS				4	9	13	15	18	18	15	16	17	4	129

MISSION MODEL TOTAL	3	11	18	26	43	47	51	52	58	53	57	55	13	487
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* ELS - Eastern Launch Site at Kennedy Space Center, Florida
* WLS - Western Launch Site at Vandenberg AFB, California

Source: NASA, 1978

CHRONOLOGY⁴⁶

1969

- 07/20/69 Apollo XI. First Lunar Landing
- 09/--/69 Presidentially mandated review of national space policy for post-Apollo period concluded that the next step should be development of space stations and low cost access to space utilizing reusable transportation system. Space Shuttle debate began in Congress.

1970

- 03/07/70 President Nixon provides endorsement of NASA's future plans--to include "*examining in greater detail the feasibility of reusable space shuttles as one way of achieving this objective* [devising less costly and less complicated ways of transporting payloads into space]."

1971

- 05/--/71 Mathematica report on Shuttle cost effectiveness.
- 06/16/71 NASA announced study of phased approach to Shuttle development.
- 07/13/71 NASA awarded Rocketdyne \$450 million Space Shuttle Main Engine (SSME) development contract.
- 12/29/71 NASA Administrator (J. Fletcher) recommends 15-by-60 foot, 65,000 pound payload capability configuration to OMB (C. Weinberger). Alternative smaller configuration (14 by 45 foot, 45,000 pound capability) if budget pressures dictate.

1972

- | | |
|----------|--|
| 01/05/72 | President Nixon issues announcement approving Space Shuttle development. |
|----------|--|
- 07/26/72 NASA selected North American Rockwell for the \$3.5 billion Shuttle Orbiter development contract.

1973

- 08/16/73 NASA selected Martin Marietta to develop the external tank for the Shuttle (\$158 million contract).
- 11/19/73 NASA selected Thiokol Chemical Corporation to develop the solid rocket motors for the Shuttle (\$106 million contract).

1978

06/20/78	President Carter issues directive stipulating that "The STS will service all authorized space users--domestic and foreign, commercial and governmental..."
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1981

04/12/81 First Space Shuttle (Columbia) launch.

1982

07/04/82	National Space Policy statement based on National Security Decision Directive (NSDD-42) released. The Space Shuttle is the "primary space launch system for both United States national security and civil government missions."
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1983

05/16/83 NSDD 94 endorses the commercialization of U.S. expendable launch vehicles.

1985

01/24/85 First dedicated DoD Space Shuttle flight.

02/25/85	NSDD 144--the National Space Strategy--directs the DoD to procure ELVs to complement the STS. These ELV's become known as Titan IV's, built by Martin Marietta.
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08/28/85 Destruction of a Titan 34D during launch.

1986

01/28/86 Space Shuttle *Challenger* destroyed during launch. Remaining Shuttles are grounded for 2½ years.

04/18/86 Destruction of a Titan 34D during launch. Titan fleet grounded.

05/03/86 Delta launch vehicle destroyed during liftoff.

08/15/86	President Reagan announces the decision to build a replacement Shuttle Orbiter and to limit the use of the STS to Shuttle-unique payloads, moving almost all commercial payloads to ELVs.
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09/05/86 Return to flight of Delta launch vehicle.

1987

01/01/87 Air Force awards contract to McDonnell Douglas for Delta IIs to serve as medium launch vehicles primarily for the Navstar (GPS) Program. GPS spacecraft offloaded from Shuttle.

03/26/87 Atlas Centaur launch failure.

03/26/87 Atlas-Centaur destroyed on liftoff by lightning strike.

08/03/87 First refurbished Titan II launchers produced.

10/05/87 Air Force announces plans for a second medium launch vehicle (MLV II) for Defense System Communications Satellites.

10/26/87 Return to flight of the Titan 34D launch vehicle.

1988

01/14/88 First Titan IV arrives at Cape Canaveral.

02/11/88	President Reagan announces a new U.S. space policy, based on NSDD 293. Stresses the use of a mixed fleet of the STS and unmanned launch vehicles. "Payloads will be distributed...to minimize the impact of loss of any single launch system...on mission performance."
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04/24/88 Air Force announces that West Coast shuttle launch facilities at Vandenberg AFB are to be mothballed.

09/05/88 First launch of refurbished Titan II.

09/29/88 Shuttle return to flight with launch of STS-26.

1989

06/14/89 First Titan IV launch.

1992

12/02/92 Last dedicated DoD Space Shuttle flight (current planning). Ninth DoD mission.

<i>Key Decisions</i>

Endnotes

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